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BELLCOMM, INC.

955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: LM-A Thermal Control System
Case 620

DATE: September 27, 1968

FROM: D. P. Woodard

ABSTRACT

The AAP lunar module (LM-A) will be used as a carrier and operations base for the AAP ATM experiment on a 56-day, earth orbit mission, a use much different from that for which its predecessor, the Apollo lunar module (LM), was designed. The mission differences affect the LM-A thermal control system.

For the most part, the passive portion of the LM thermal control system is adequate for the AAP environment. Higher α_s/ε coatings have been chosen to minimize heat loss during the inherently colder mission. RCS plume deflectors have been added to protect the ATM solar arrays. The thermal skins have been changed to accommodate different plume impingement patterns.

The active portion of the LM thermal control system has been modified extensively. An external radiator system will be used for waste heat rejection during ATM data taking periods. Numerous changes to the environmental control system (ECS) also influence the active thermal system design.

(NASA-CR-97700) LM-A THERMAL CONTROL SYSTEM (Bellcomm, Inc.) 31 p

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MEMORANDUM FOR FILE

Introduction

The AAP Lunar Module (LM-A) is a derivative of the Apollo Lunar Module (LM), which will use a modified ascent stage as a carrier and operations base for the AAP ATM experiment. The AAP LM-A mission differs considerably from the Apollo Lunar Mission in total mission duration, in expected external environment, and in the ATM operations the LM-A must support.(1,2) Numerous modifications have been necessary to adapt the LM to the new requirements imposed by the ATM mission. Some of the changes to the external configuration are apparent from a comparison of Figures 1 and 2.

We are concerned here with the thermal design of the LM-A. From this viewpoint, the approach has been to utilize the basic Apollo LM thermal capability to its fullest extent, modifying the design only as required. Although the changes have been extensive, particularly to the active portions of the thermal control subsystem, much of the basic thermal design philosophy for the Apollo LM has been inherited by the LM-A. The LM design approach, the new requirements imposed by the AAP mission, the thermal environment of an extended earth orbit mission, and the resulting changes to the basic Apollo vehicle provide a framework to describe the LM-A Thermal Control Subsystem as presently baselined.

The information contained in this description is based on preliminary reports originating from Grumman Aircraft and Engineering Corporation (GAEC). Changes may occur at the Preliminary Design Review (PDR) scheduled in October, as the mission requirements continue to evolve, and as the induced and natural thermal environment is better defined.

Apollo LM Design Approach

Both passive and active measures are used to establish and control temperatures of the basic LM vehicle over a wide range of external thermal inputs and internal power levels. Thermal extremes expected during translunar flight and lunar stay make these mission phases critical to the thermal design.

Roll maneuvers, following unrestricted hold orientations, will be employed during the translunar phase to reduce temperature differences. However, the LM thermal design must be adequate for a landing anywhere on the lunar surface with any insolation direction.* The resulting extremes, coupled with alternating periods of high and low internal activity levels, require considerable flexibility in the LM thermal control subsystem.

The basic thermal control philosophy selected by the LM designers is to isolate the vehicle interior from the exterior environment by passive means and to employ active measures to remove excess heat from the vehicle interior. The passive design consists of an assemblage of external thermal shields or skins with an underlying insulation blanket. The combination is chosen to maintain internal structure and equipment temperatures within the limits shown in Table 1.[3,4] Maintaining temperatures within these limits restricts the heat loads the active portion of the system is required to handle. The skins must have sufficient thermal mass, optical properties, and temperature characteristics to provide an acceptable temperature boundary for the environmental extremes, including protection for plume impingement and engine firings, and to protect the fragile insulation blanket. In addition to providing thermal isolation, the insulation blanket must be capable of venting the large volume of air contained in the LM during the first few minutes after launch without blanket damage. When the LM is in space, internally generated gas must be free to escape through the blanket. Figure 3 shows a typical cross section of the passive protection scheme and indicates some of the measures employed to minimize thermal leaks where penetrations and skin supports are required.[5] Insulation and skin vents are also indicated. Test results reported by Grumman Aircraft and Engineering Corporation (GAEC) indicate an overall blanket effective emittance** of 0.01 for the LM ascent stage.[3]

The active portion of the LM thermal control subsystem consists of a closed ethylene glycol-water coolant loop which removes waste heat from the suit and cabin atmospheres via heat exchangers and controls the temperature of equipment through a coldplate network. The heat is transported by the coolant to a water sublimator where it is rejected from the vehicle. Heat rejection by water sublimation is optimum for the short duration lunar mission since the quantity of water required is not prohibitive when balanced against the resultant simplicity. A secondary coolant loop, designed to handle essential loads only, is provided for reliability. Primary heat loads predicted for the Apollo lunar mission range from 2600 BTU/hr to approximately 10,200 BTU/hr.[6]

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* A daylight lunar landing is presently planned; however, the original design objective was to permit either a day or night landing by changing optical coatings.

** ε_{eff} as defined by $Q = \sigma\varepsilon_{eff}(T_{in}^4 - T_{out}^4)$ BTU/hr ft^2

LM-A Requirements

The requirements that affect the LM-A thermal design have been extracted from the Environmental Control System (ECS) requirements [7] and listed in the Appendix. The list is summarized in the following paragraphs:

1. Water sublimation will be used to reject waste heat during all pre-ATM activation phases (boost, rendezvous, and docking) as well as metabolic loads during extravehicular activity (EVA). During pre-launch, heat will be rejected by GSE Freon evaporation. Cooling by water sublimation will not be permitted during active ATM experiment periods.

2. All EVA will be conducted from the LM-A cabin, and performed by two men. The maximum EVA duration will be 3.5 hours with a .5 hour contingency. The LM-A will support a maximum of 32 man-hours of EVA.

3. The primary mode of operation while docked to the OA or CM-SM will be "open-hatch." The LM-A will be manned by at least one crewman with the exception of occasional periods and weekly recreation and relaxation days.

4. The LM-A two-gas atmosphere (oxygen and nitrogen) will be provided by the CM-SM during normal, open-hatch operations using forced air exchange. The cabin atmosphere temperature will be actively controlled by the LM-A thermal control equipment. Isothermal gas exchange between the LM-A and OA, or CM-SM, is assumed for design purposes. Humidity, CO_2, odors, and particulate matter will be controlled by the OA or CM-SM.

5. The only physical thermal control equipment interface between the LM-A and the ATM is the ATM controls and displays console(CDC). The CDC heat load will be no greater than 384 watts peak (257 watts DC, 35 watts DC growth allowance, and 92 watts AC). Active cooling will be used to control the panel to temperatures consistent with NASA crew comfort criteria. No more than 77 watts (20%) of the C&D panel heat load will be transmitted to the cabin atmosphere.

6. An active heat transport network will be provided to control the temperature of the LM-A cabin, electronic equipment, the ATM CDC panel, and the EVA LCG's. Normally this network will transfer heat to external radiators for rejection to space except for periods when water sublimation is permitted.

For the most part, these requirements determine the thermal design of the LM-A.

LM-A Passive Thermal Control

As in the LM, the passive portion of the LM-A thermal control system is designed to isolate the vehicle interior from its external environment, whether natural or induced. During pre-launch operations, the LM-A is inside the SLA; an ambient temperature range from 30° to 100°F is probable;[3] and the LM-A surface temperatures are controlled by ground support equipment (GSE). During boost and until withdrawal of the LM/ATM from the SLA, exterior temperatures should not exceed 375°F. The short duration of this phase should have little effect on LM-A temperatures.

Environmental factors for the earth orbit AAP mission are: solar, earth albedo, and earth infrared radiation; the infinite heat sink of free space; infrared interchange with other components of the orbital assembly or CM-SM and ATM; and reaction control system plume impingement. GAEC has computed the approximate heat flux incident on the LM-A exterior due to the sun, earth albedo, and IR emission, based on a cubic representation of the vehicle surface.[8]* Maximum and minimum orbital average heat fluxes incident on the six sides are shown in Figures 4 and 5 for both solar and local vertical flight orientations and as a function of the solar vector/orbit plane inclination, θ_s. Although the analysis does not include effects of shading by other parts of the OA or CM-SM and radiant exchange between surfaces, the maximum and minimum flux values are comfortably within the range that would exist on the lunar surface for the Apollo LM.

The basic Apollo LM passive system is thus retained by the LM-A. The LM-A design diagrammed in Figure 6, which corresponds closely to the LM design of Figure 3,**shows the skin and insulation buildup for low, medium and high temperature surfaces. The number of layers of aluminized H-film and mylar depends on the temperature expected. The nickel foil layers, separated by inconel mesh spacers, and the outermost inconel skin, which can tolerate higher temperatures, are used in areas where plume impingement is expected. Temperatures for these surfaces are limited by a radiation coating of silicone

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* The external configuration of the LM-A has been continually evolving during the design phase, and its representation as a cube for incident flux computations has been a practical and realistic approximation for this phase. A more detailed analysis recently completed by GAEC uses a more sophisticated model and includes shadowing effects. These data will be available at the PDR.

** The basic LM design is described in more detail in Reference 5.

paint which has a solar absorptivity to emissivity ratio, α_s/ε, close to unity.*

For non-plume impingement exterior surfaces, the 4 or 8 mil aluminum skin is anodized. The resulting α_s/ε ratio, between 1.0 and 1.5, minimizes the LM-A heat loss during the extended earth orbit mission without causing excessive skin temperatures during the pre-docked phase when the incident flux is somewhat greater than shown in Figures 4 and 5.** Surface coatings are given in Table 2.

The passive system design has not been completed in all details due to the continued change in the LM-A external configuration during this design period. When the geometry is firm, a more detailed environmental analysis will be performed and the design details completed.

The RCS plume deflectors are also a proper part of the LM-A passive thermal system. The deflectors are shown in Figure 1 and are arranged to direct the -X RCS exhausts away from the ATM.*** During unmanned rendezvous and docking, the folded ATM solar panels are particularly vulnerable to heating and contamination by the exhaust gasses.

The deflectors are limited in size since they must fit inside the SLA envelope during launch. Maximum effectiveness results when the exhausts are deflected close to the nozzle. This, however, requires the use of columbium with a ceramic coating to withstand the high exhaust temperatures. The present design is shaped like a section of a conic frustum.

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* $\alpha_s/\varepsilon = \dfrac{.88 \pm .03}{.82 \pm .04}$

** $\alpha_s/\varepsilon = \dfrac{.42 \pm .03}{.35 \pm .05}$

*** Seventeen RCS firing periods greater than 5 seconds are planned during unmanned rendezvous and docking. The total RCS firing time is approximately 4 minutes.

LM-A Active Thermal Control/Environmental Control

The requirements for EVA LCG cooling, the restricted use of water sublimation as a heat sink, the almost complete LM-A thermal independence from the other AAP modules,* and unmanned rendezvous and docking (URD) have resulted in extensive modifications to the original Apollo LM active thermal control. The environmental control subsystems (ECS) involved are:

1. Oxygen Supply and Cabin Pressure Control Section (OSCPCS)**

2. Atmosphere Exchange and Cabin Ventilation Section (AECVS)

3. Heat Transport Section (HTS)

4. Water Management Section (WMS)

5. Cold Plate Section

6. Liquid Cooled Garment Support Section (LCGSS).

OSCPCS

The oxygen supply and cabin pressurization control section functional schematic is shown in Figure 7. During unmanned rendezvous and docking, its purpose is to store and regulate oxygen to provide a reference pressure to the WMS for water sublimator control. The two gaseous O_2 accumulators (type 319) are charged to 850 psia, minimum, and accumulate approximately 14 lbs each. Regulation and flow to the "Ref. Pressure Source Assembly" is shown.

After docking, the section accumulates and regulates O_2 transferred from the CM-SM for use during EVA and for cabin repressurization afterwards. The transfer rate from the CM-SM is 15 lbs/hr and oxygen is used directly from the CM-SM supply unless this demand is exceeded. The section capacity is sized to provide for a 3.5 hour, 2 man EVA at 8 lbs/hr/man, plus a 0.5 hour torn suit condition at 8 lbs/hr, and a subsequent 8 lb cabin repressurization.

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* Over the past several months, a number of studies have been made to determine the desirability of a dormant LM-A, i.e., thermal control provided entirely or partially by the active CM-SM system. As baselined, the LM-A is thermally independent of the OA or CM-SM systems except for latent heat removal, which occurs via forced air exchange during normal mission operations.

** The OSCPCS is not directly involved in thermal control but is included here for completeness.

Flow paths, regulation, check valves, etc., are shown on the schematic to supply the pressurization control unit (PCU) during EVA, for the pre-breathing masks prior to EVA, and for subsequent cabin repressurization. The PCU's are open systems; that is, there is no O_2 return.

AECVS

The atmosphere exchange and cabin ventilation section consists of an exchange duct and distribution plenum. After docking, the duct is installed by the crew to couple atmosphere from the OA or CM-SM to the plenum for discharge into the LM-A cabin. The arrangement is indicated in Figure 8.

HTS, CPS, and HRS

Excess heat is removed from all electrical and electronic equipment by the heat transport section,which uses a glycol-water mixture as the transfer coolant. The high specific heat coolant is coupled to the heat sources by the coldplate section. During prelaunch and boost, heat is transferred from the coolant to two GSE freon boilers (type 221).* A water sublimator (type 209) is activated during ascent (approximately 120,000 feet). The section is shown in Figure 8.

After rendezvous and docking, the heat rejection section is activated by the crew. The HRS removes heat from the HTS via two transport fluid heat exchangers (type 204) and transports it to an external radiator network for rejection from the vehicle. The HRS uses a low freezing point ($-80^{\circ}F$), low viscosity, fluorocarbon (FC-75) as the working coolant. Regeneration and by-pass controls (coolant regenerative heat exchanger, type 204 and temperature control valve, Figure 8) are used to prevent stagnation of the glycol-water coolant (freezing point $0^{\circ}F$) in the HTS loop heat exchangers. Coolant recirculation assemblies (type 290) are used in both loops.

After HRS activation and during subsequent normal operations, the ATM controls and display console (CDC) and the cabin heat exchanger (type 101) are added to the HTS loop heat loads. The cabin atmosphere is controlled to $70^{\circ} \pm 5^{\circ}F$ through this exchanger.

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* The type numbers are given to help identify the components on the functional schematics. For further operation and performance details, refer to reference 6.

The external radiators are composed of four separate panels located fore and aft of the LM-A. The forward panels, located on either side of the forward hatch, have an area of 10 ft^2 each. The two aft panels have an area of 40 ft^2 each. The lower aft panel is movable prior to launch to permit access to equipment (ERA rack) behind it. Radiator by-pass and regenerative controls are used to limit the HRS fluid temperature at low heat loads. Expected loads are summarized in Table 3. The HTS secondary loop components are expected to be deleted (Figure 8) since requirements no longer exist for its operation.

WMS

The water management section stores, pressurizes, and distributes water as needed during the LM-A mission. A functional schematic is shown in Figure 9.

Prior to ATM and HRS activation, the WMS supplies water to the LM-A water sublimator (type 209) for heat rejection. During EVA, water is also supplied to the LCG sublimators to reject the metabolic load.

Water is stored in 4 LM ascent stage water tanks (type 409) which have a usable capacity of 40 lbs each. The tanks consist of an aluminum outer shell, standpipe, and a silicone rubber bladder. Water is contained in the bladder and the volume between the shell and bladder is charged with nitrogen at 50 psia. The tanks are charged before launch and are sized to supply all water requirements. The capability exists for recharge from the CM-SM at 20 to 25 psia; however, no CM-SM recharge requirement is contained in the baseline.

Water is supplied by the water module (type 490) at a pressure of .5 to 1.0 psi above cabin atmosphere pressure. The flow limiters (type 425) are used to attenuate the initial water surge to the sublimators when the shut-off valves (type 420) are opened.

LCGSS

The liquid cooled garment support section controls water flow and temperature to the LCG and is shown in Figure 10. Two independent networks are provided to prevent both EVA crewmen from being affected by a single failure. Water is circulated by LM recirculation assemblies (type 290) in each loop. Heat is rejected by evaporators (type 224). The LCG by-pass valves and heaters permit operation after EVA operations to dry out the evaporators. Water is provided from the WMS.

The general arrangement of the ECS components is shown in Figure 11. An operational summary of the ECS sections is given in Table 4.

D. P. Woodard

1022-DPW-ms

Attachments.

References

1. Baseline Configuration Definition Document, AAP-1 through AAP-4, September 1, 1968.

2. Universal Mission Modular Data Book, LED-500-19, October 15, 1967.

3. Tawil, Bartilucci, Lee, "LM Passive Thermal Design and Test," AIAA Paper No. 68-748, June 1968.

4. GAEC/Bellcomm Conference, September 12, 1968.

5. Haron, A. S., "LM Thermal Control System Description and Status," Bellcomm Memorandum for File, June 3, 1968.

6. LSG 770-430-42-LM-3, "Environmental Control Subsystem Study Guide, Lunar Module, LM-3," February 1968.

7. LM-A ECS Requirements, ARP254-1, REV. E., GAEC, July 3, 1968.

8. LM-A Orbital Heating Environment, ARP251-2, GAEC, May 17, 1968.

9. LM-A Thermal Control Technical Meeting at MSC, July 17, 1968.

APPENDIX

LM-A Thermal Control Requirements

Reference ARP 254-1 Rev. E, 3 July 1968

A. Established Requirements

1. During normal mission operations while docked to the OA or CSM, LM-A is manned by at least one man with the exception of occasional periods. About one out of every seven (7) days may be reserved for crew recreation and relaxation when the LM-A would be unoccupied for a complete day.

2. The primary mode of operation is "open hatch" while docked to the OA or CSM during the experiment period.

3. During "open hatch" operations, the LM-A will be provided a controlled two-gas (oxygen and nitrogen) or pure oxygen atmosphere. The OA or CSM shall remove metabolic carbon dioxide, excess water vapor, odors and particulate matter from the LM-A atmosphere during "open hatch" operations by forced atmosphere exchange. During EVA operations the LM-A shall provide pure oxygen only to maintain cabin and spacesuit pressure.

4. The CSM/LM-A interfaces for the Docked CSM-LM/ATM Mission are identical to OA-LM/ATM Baseline Mission interfaces.

5. All EVA is performed by two men. Maximum EVA duration will be 3 1/2 hours with a 1/2 hour contingency.

6. EVA shall be from the LM-A cabin with LM-A supported PCU/LCG with umbilicals. (verbal conversation with R. L. Frost)

7. There are no physical ECS interfaces between the LM-A and the ATM except for the GFE ATM C&D panel interfaces noted herein.

8. ATM controls and display console heat loads shall be no greater than 384 watts peak, exclusive of the LM-A inverter, Lighting Control Assembly, and distribution losses. This maximum 384 watt power level shall consist of no more than 257 watts DC with a 35 watt DC growth allowance and no more than 92 watts AC. Active cooling shall be provided for the console to the extent that:

   (a) No more than 77 watts of ATM console heat load is transmitted to the LM-A cabin atmosphere.

   (b) ATM console panel temperatures are controlled to levels that are consistent with NASA crew comfort criteria.

9. The LM-A ECS configuration shall support the launch, rendezvous and remote docking of an active, unmanned LM-A as follows:

   (a) Freon cooling during prelaunch operations.

   (b) Activation of water sublimator during boost phase.

   (c) Sublimator cooling from sublimator activation through rendezvous and docking.

10. The ECS shall actively control the temperature of the LM-A cabin during all manned operations. The temperature of the cabin atmosphere shall be controlled to levels that are consistent with NASA crew comfort criteria as defined by the MSC Biomedical Research Office. Isothermal gas

exchange between the LM-A and MDA/AM or CSM shall be assumed for design purposes.

11. The LM-A ECS shall provide for the thermal control of LM-A electronic equipment and ATM C&D panel for all active mission phases.

12. The LM-A ECS shall be capable of rejecting all LM-A heat loads without water supplement during ATM data taking operations when LM/ATM is docked to the OA or CSM.

13. The LM-A ECS shall control the temperature of water entering the Liquid Cooled Garment (LCG) to between 40 and 45°F during all EVA requiring egress from the LM-A cabin.

14. The LM-A radiator fluid shall be FC-75.

15. The water management equipment shall store, condition (pressure regulation) and distribute water as follows:

    (a) To LM-A water sublimators during mission phases prior to ATM activation for rejection of all LM-A waste heat.

    (b) To the LM-A LCG water sublimators for rejection of metabolic heat during a maximum of 32 man-hours of LM-A supported EVA.

B. Assumed Requirements

None

C. Undefined Requirements

1. Detailed definition of ATM C&D panel active cooling configuration for thermal control analyses to minimize impact on cabin temperature and crew comfort is required.

2. Definition of the temperatures and emissivities of all surfaces of the OA which are viewed by LM-A is required.

3. ATM experiment constraints on water sublimation during EVA require definition.

4. PCU supported EVA equipment and egress procedures require definition.

5. Procedures and requirements to verify proper operation of all LM-A EVA life support systems prior to LM-A depressurization need definition.

6. The requirement for LM-A cabin and tunnel repressurization from 0 to 3 psia in one (1) minute from the LM-A accumulator system and/or CSM or MDA (Ref. 44) cannot be met without redesign. The requirement therefore needs resolution.

<u>Table 1</u>

<u>LM Temperature Limits</u>

Internal Structure	30 to 130°F
Propellant	40 to 90°F
Batteries	30 to 130°F
Cabin Oxygen	60 to 90°F
Water	32 to 100°F
External Skins	-350 to +350°F

Table 2

LM-A External Coatings

Coating	α_S	ε	Location
S-13G	$.18 \begin{smallmatrix} + .12 \\ - .0 \end{smallmatrix}$	.85 ± .05	Radiators
Pyromark	.88 ± .03	.82 ± .02	RCS Cluster Mount, some areas of high plume impingement TBD.
Vacuum Deposited Al on H-Film	.15	.05	Bottom of Mid-Body
Silicide	.8	.8	Plume Deflectors
Moly Disilicide	.9 ± .03	.45 ± .04	RCS Engines
Anodized Aluminum	.42 ± .03	.35 ± .05	Balance of Vehicle

Table 3

LM-A Active System Heat Loads

	Baseline Mission		Alternate Mission	
	Typical Day	EVA Day	Typical Day	EVA Day
	watts	watts	watts	watts
Cabin H/X Load	349	101	353	106
ATM C&D Panel	223	17	223	17
Essential C&D Support Equip.	100	56	100	56
LM-A Communications and Instrumentation	39	39	105	105
Pumps	31	31	31	31
LCG Metabolic	0	1170	0	1170
	742	1414	812	1485

TABLE 4
ECS OPERATIONAL SUMMARY

MISSION PHASE / FUNCTION	THERMAL CONTROL	HEAT REJECTION	OXYGEN SUPPLY & CONTROL	CABIN VENTILATION
1. PRE-LAUNCH	ACTIVE TO PROVIDE LM-A EQUIP COOLING	FREON BOILERS	ACTIVE TO PROVIDE SUBLIM WATER REQ'R REF PRESS	INACTIVE
2. LAUNCH & BOOST		WATER SUB-LIM. ACTI-VATED BY ON-BOARD COMMAND		
3. RENDEZVOUS				
4. DOCKING				
5. POST DOCKING	ACTIVE TO PROVIDE: -LM-A EQUIP COOLING-CABIN TEMP CONTROL -ATM C&D COOLING	WATER SUB-LIM SHUT-DOWN, CREW ACTIVATION OF RADIATOR NETWORK	DE-ACTIVATED BY CREW SUBSEQ. TO SUBLIM SHUTDOWN	CREW ACTIVA-TION OF CABIN FANS, IN-STALL'N OF ATMOS. EXCH. DUCT
6. ATM ACTIVATION		RADIATORS		
7. EXPERIMENT				
a. EXP OPS b. EVA		RADIATORS, CREW ACTI-VATION OF LCG WATER SUBLIM.	ACTIVATED BY CREW FOR PCU SUPPORT CABIN REPRESS	DEACTIVATED BY CREW FOR EVA

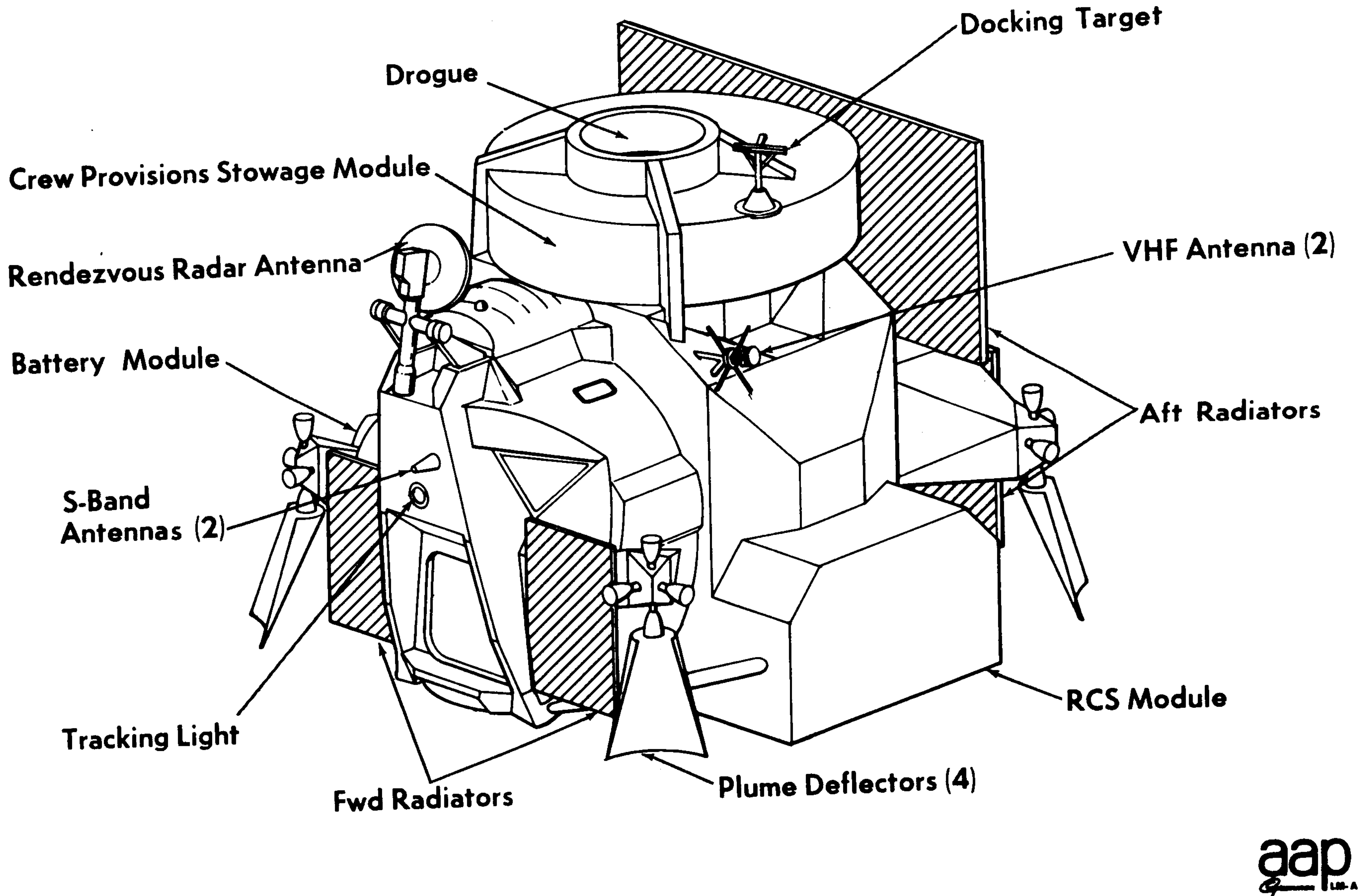


FIGURE 1. LM-A EXTERNAL CONFIGURATION

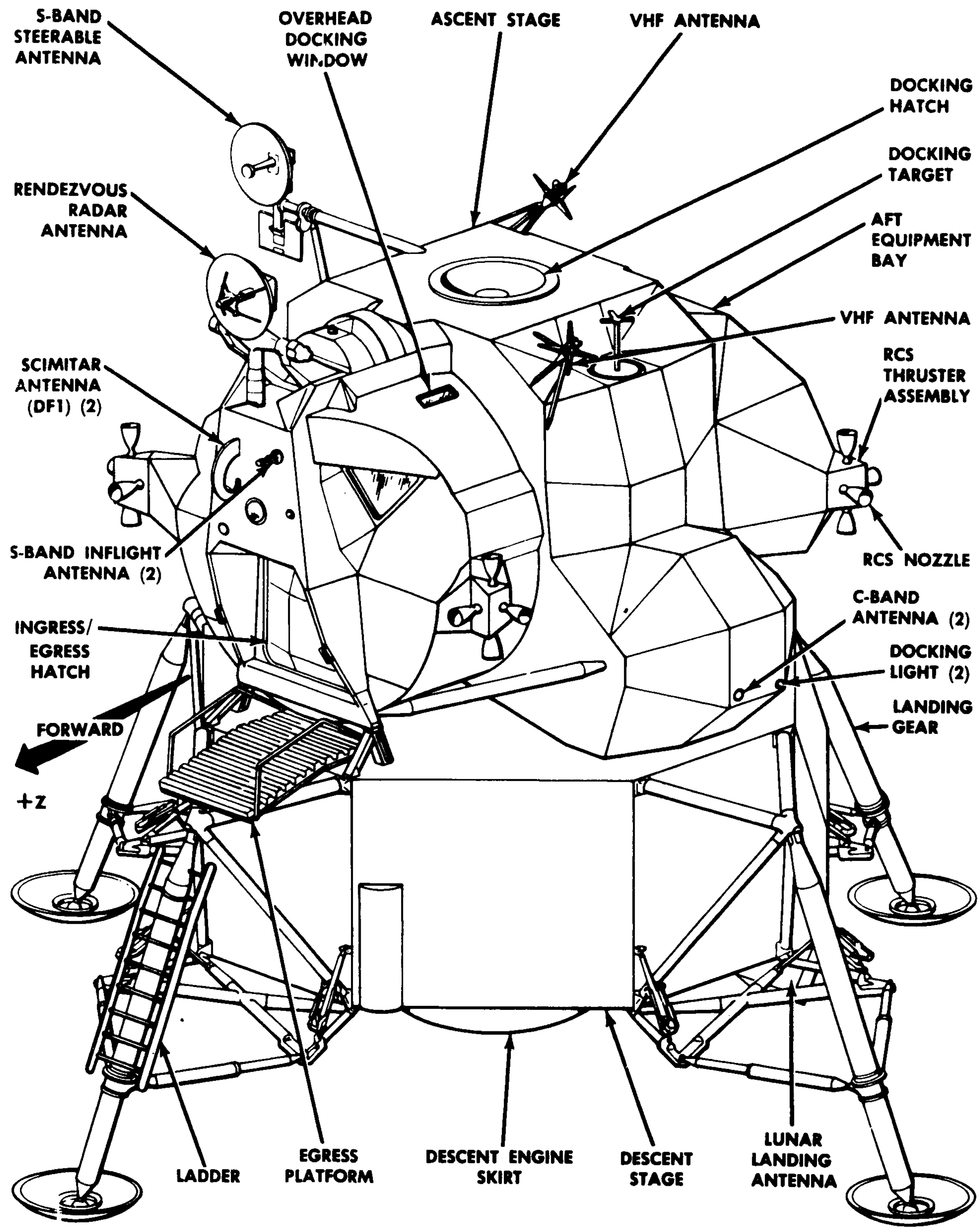
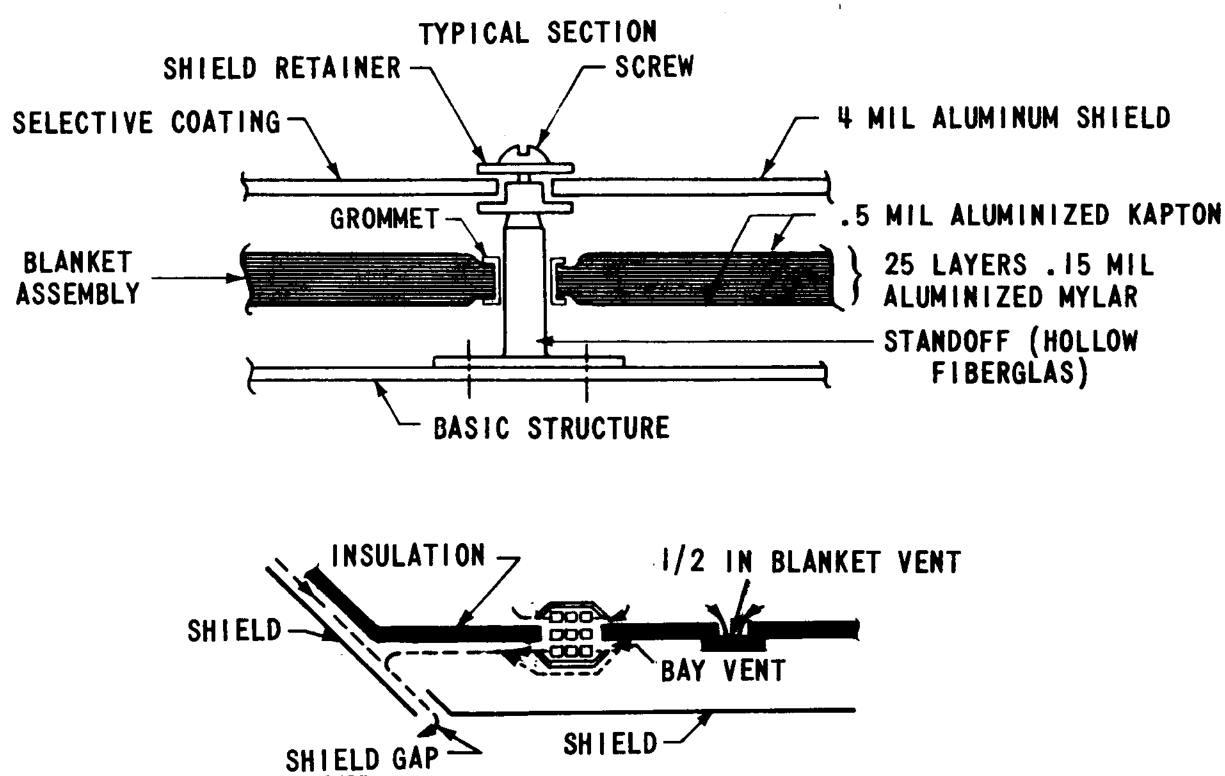


FIGURE 2. LM2 CONFIGURATION



NOTES:

1. STANDOFFS HAVE LOW THERMAL CONDUCTIVITY AND ARE COATED TO MINIMIZE RADIATION.
2. HIGH CONDUCTIVITY PENETRATIONS, ANTENNAS, ETC., ARE INSULATED AND/OR COATED TO MINIMIZE THERMAL LEAKS.
3. CABIN WINDOWS HAVE INTERNAL, REFLECTIVE SHADES.

FIGURE 3 - LM BASIC THERMAL PROTECTION SYSTEM

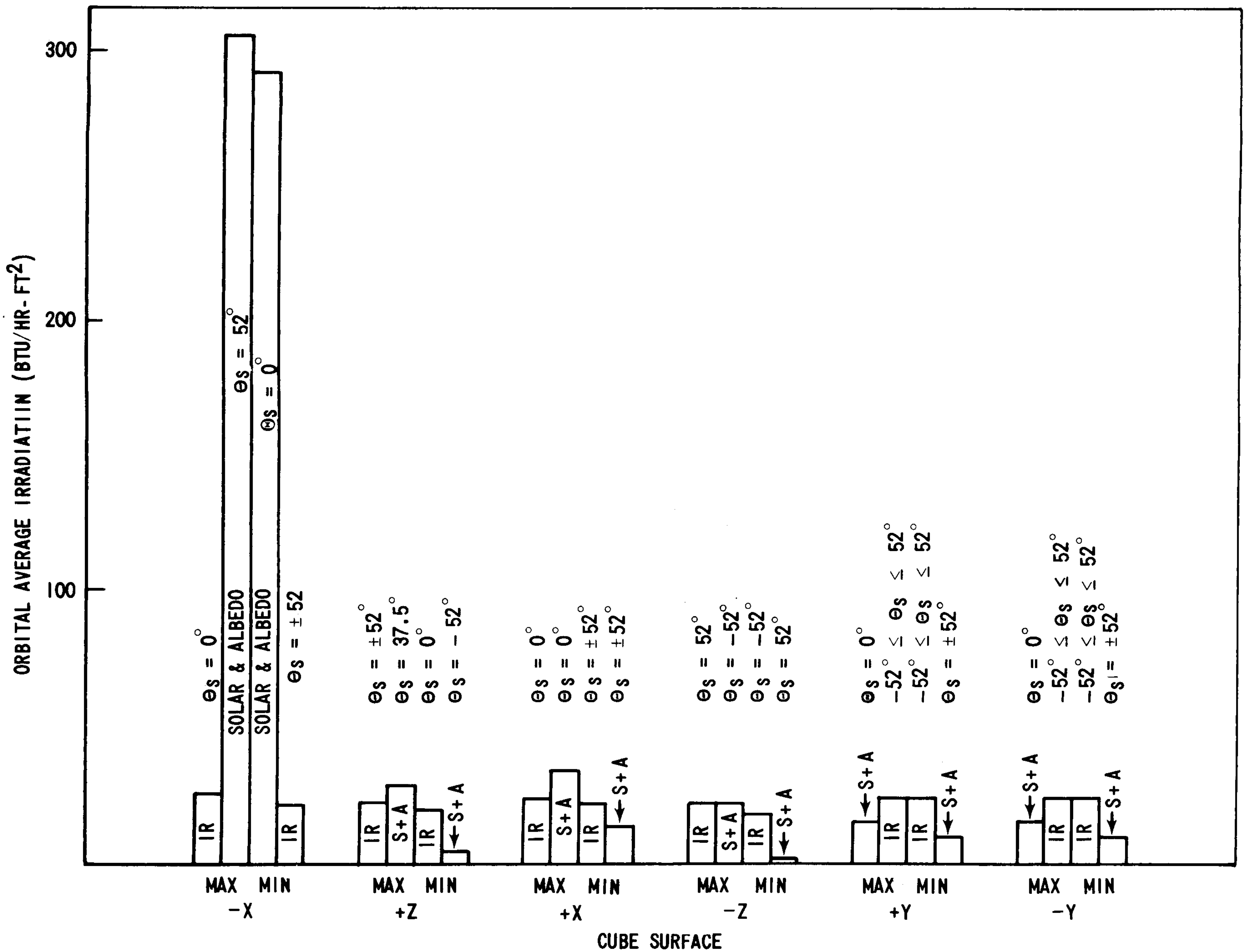


FIGURE 4. MAXIMUM & MINIMUM ORBITAL AVERAGE IRRADIATION SUN ORIENTED CUBE

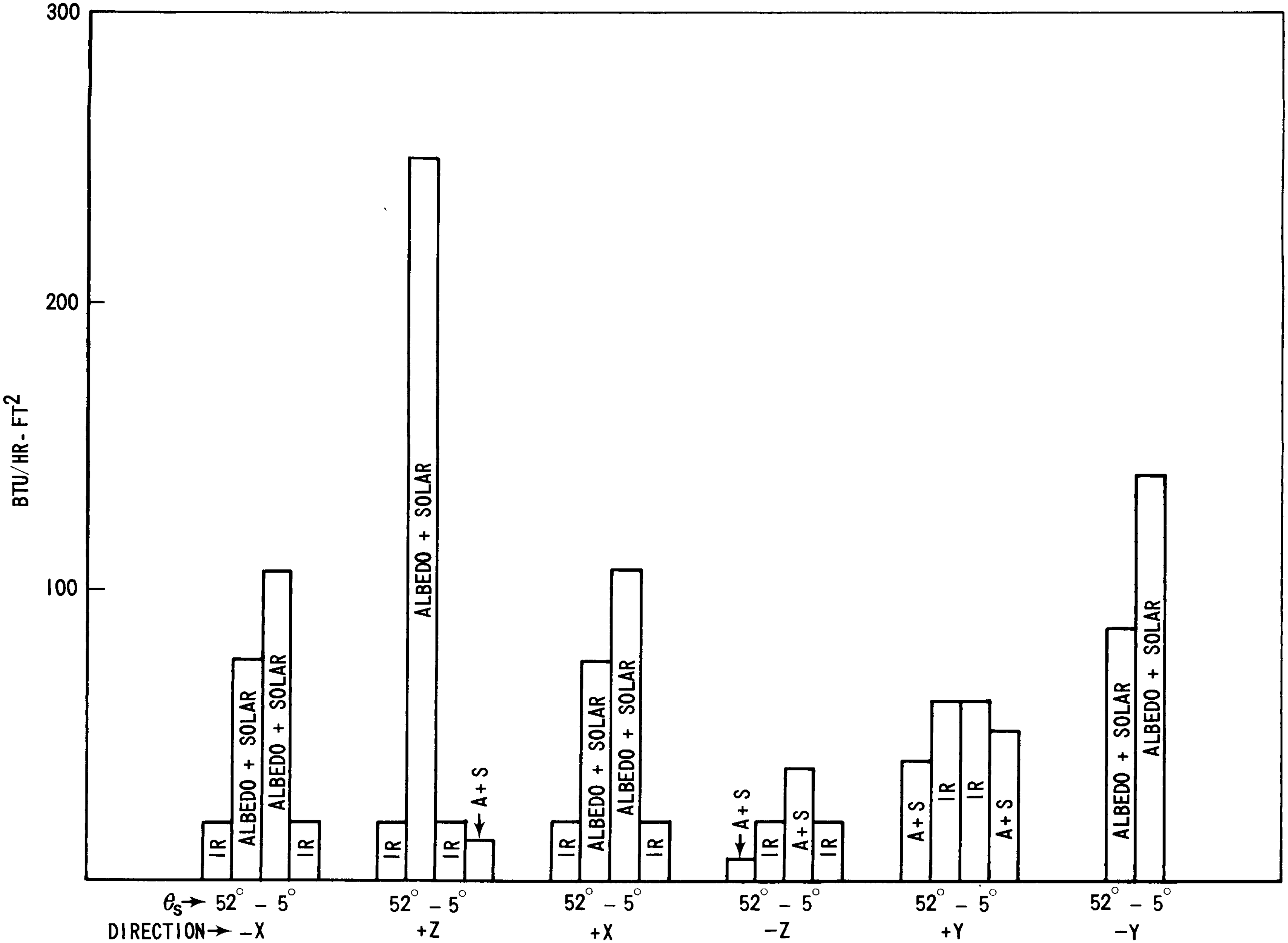
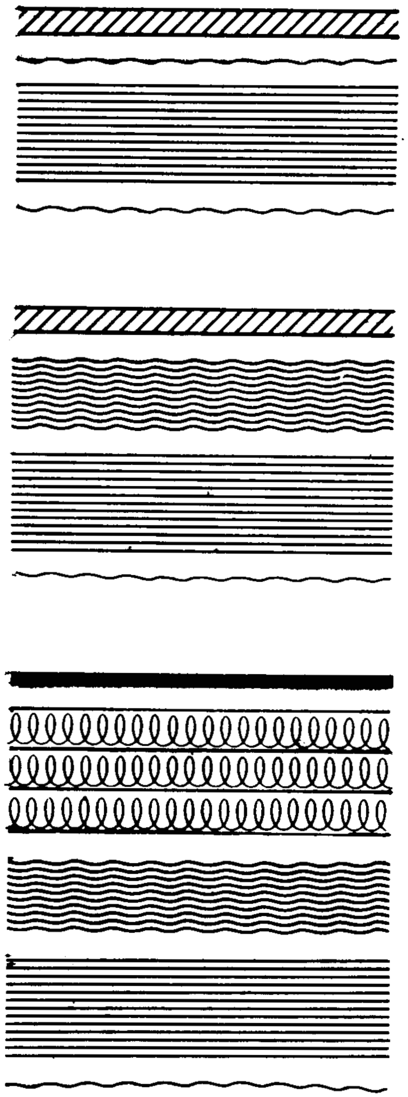


FIGURE 5. ORBITAL AVERAGE IRRADIATION
LOCAL VERTICAL CUBE



375°F MAX
700°F MAX
375°F MAX
2000°F MAX
750°F MAX

LOW TEMPERATURE BUILDUP

I SKIN AL 4 TO 8* MILS
I LAYER H-FILM .5 MIL
24 LAYERS MYLAR .15 MILS
I LAYER H-FILM .5 MIL

STANDARD BLANKET SKIN DESIGN W/O PLUME IMPINGEMENT OR LIGHT PLUME IMPINGEMENT
375°F LIMIT SET BY SHRINKAGE
NOTE: H-FILM & MYLAR ALUMINIZED ON ONE SIDE

MEDIUM TEMPERATURE BUILDUP

I SKIN AL 4 TO 8* MILS
25-N LAYERS H-FILM .5 MIL
N LAYERS MYLAR .15 MIL
I LAYER H-FILM .5 MIL

MILD PLUME IMPINGEMENT
AL SETS SURFACE TEMP.
N DETERMINED BY INSULATION NEEDED TO DROP TEMP THROUGH H-FILM TO 375°F AT SURFACE OF MYLAR

*BASED ON HEAT SINK CONSIDERATIONS

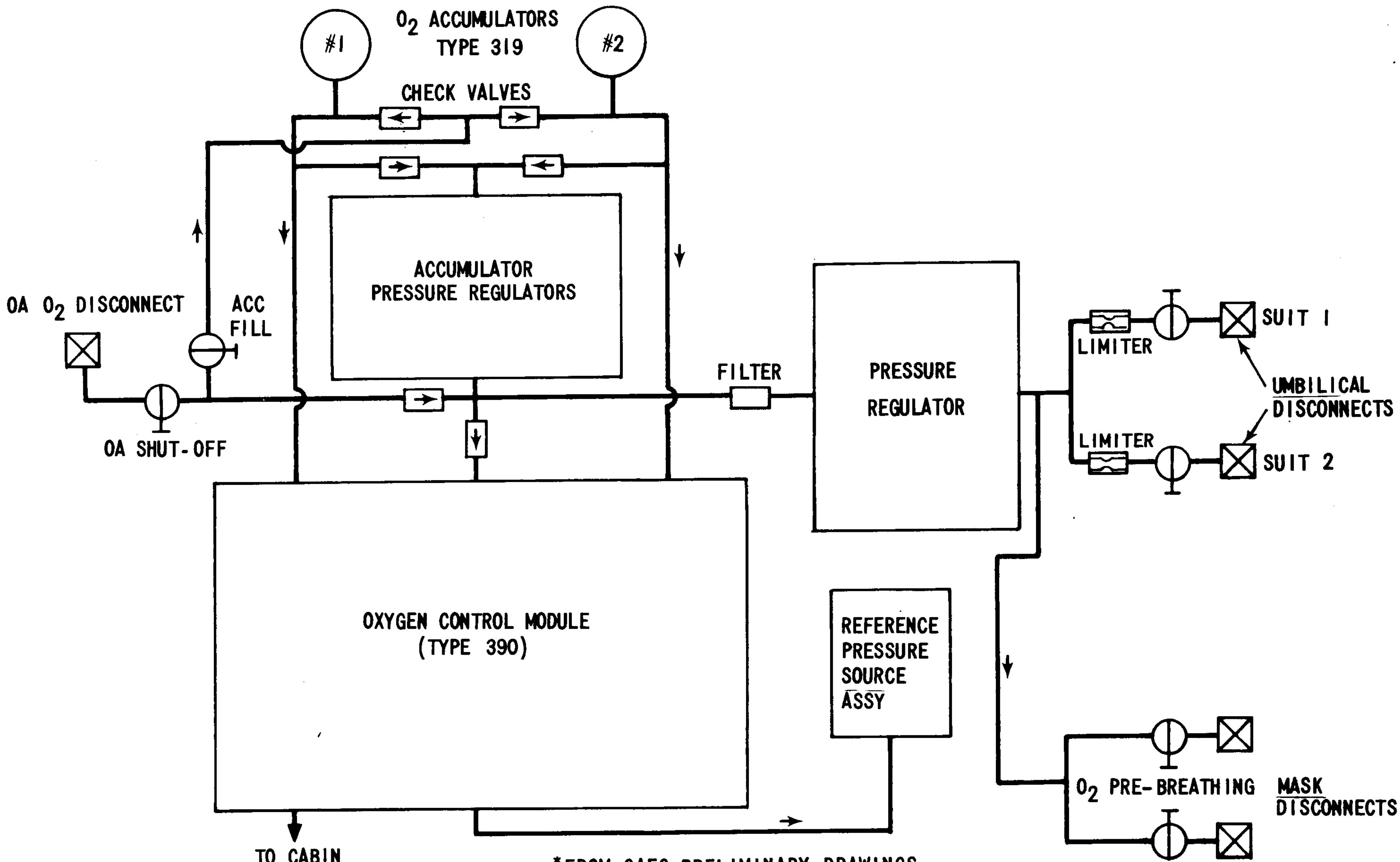
HIGH TEMPERATURE BUILDUP

I SKIN INCONEL 1.25 MIL
M LAYERS NICKEL .5 MIL
M-I LAYERS INCONEL MESH
25-N LAYERS H-FILM .5 MIL
N LAYERS MYLAR .15 MIL
I LAYER H-FILM .5 MIL

HIGH PLUME IMPINGEMENT
M MUST BE SUFFICIENT TO DROP TEMP TO 750°F AT H-FILM INTERFACE

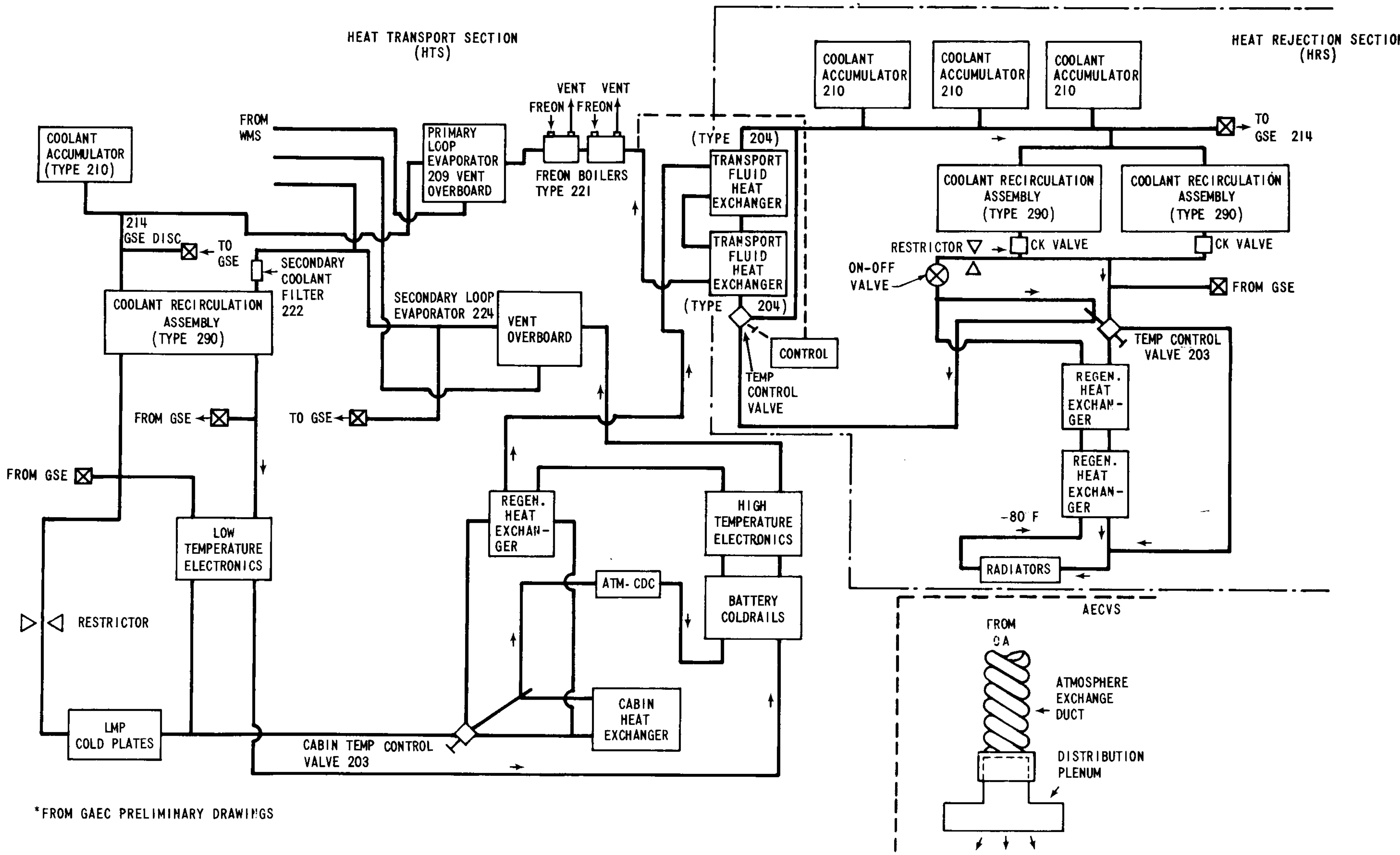
(GAEC PRELIMINARY INFORMATION)

FIGURE 6 - LM-A SKIN AND INSULATION DETAILS



*FROM GAEC PRELIMINARY DRAWINGS

FIGURE 7. OXYGEN SUPPLY AND CABIN PRESSURIZATION CONTROL SECTION FUNCTIONAL DIAGRAM



*FROM GAEC PRELIMINARY DRAWINGS

FIGURE 8. HEAT TRANSPORT, HEAT REJECTION & ATMOSPHERE EXCHANGE AND CABIN VENTILATION SECTIONS – FUNCTIONAL DIAGRAM

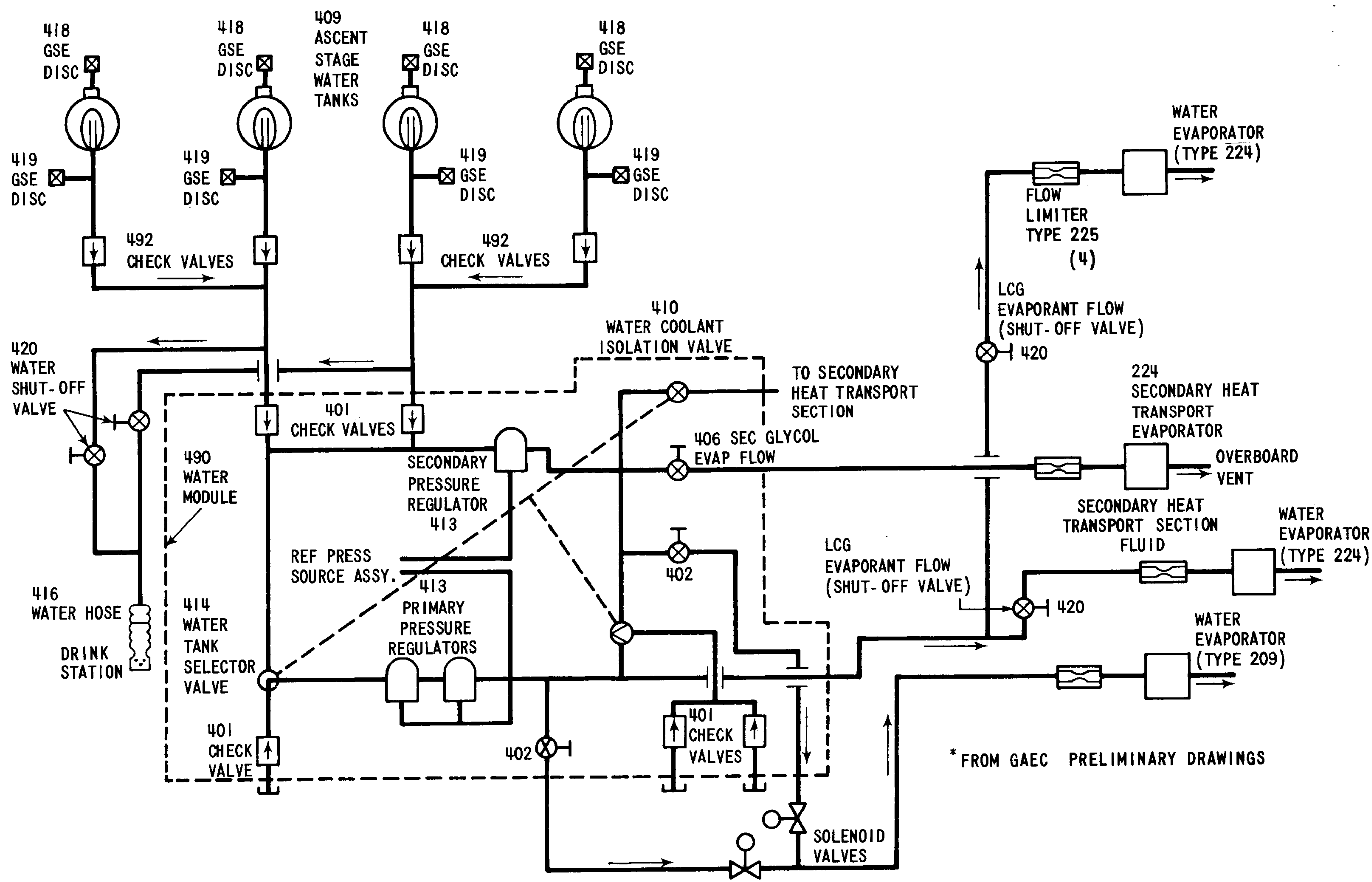
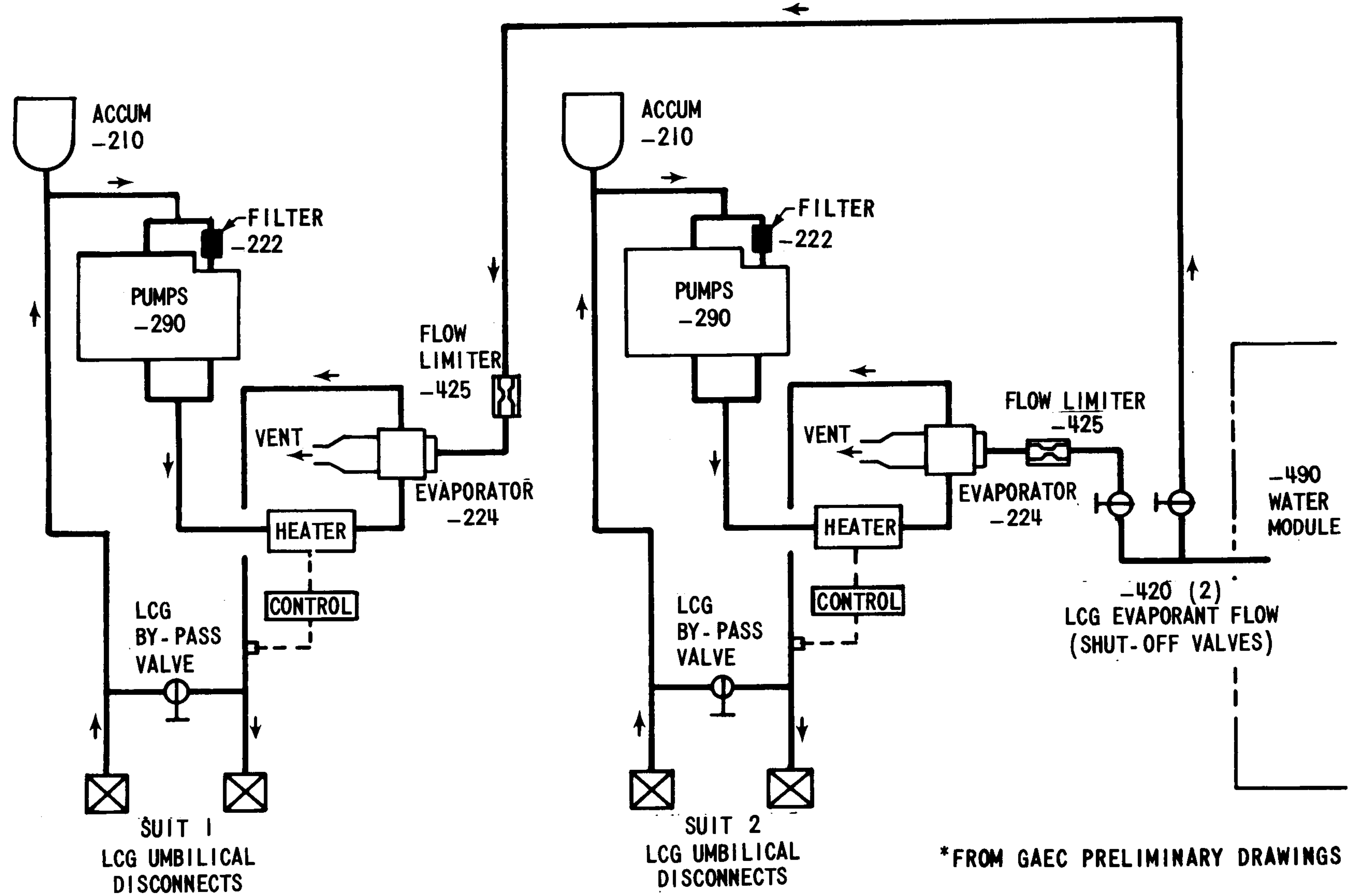


FIGURE 9. WATER MANAGEMENT SECTION FUNCTIONAL DIAGRAM



*FROM GAEC PRELIMINARY DRAWINGS

FIGURE 10. LIQUID COOLED GARMENT SUPPORT SECTION FUNCTIONAL DIAGRAM

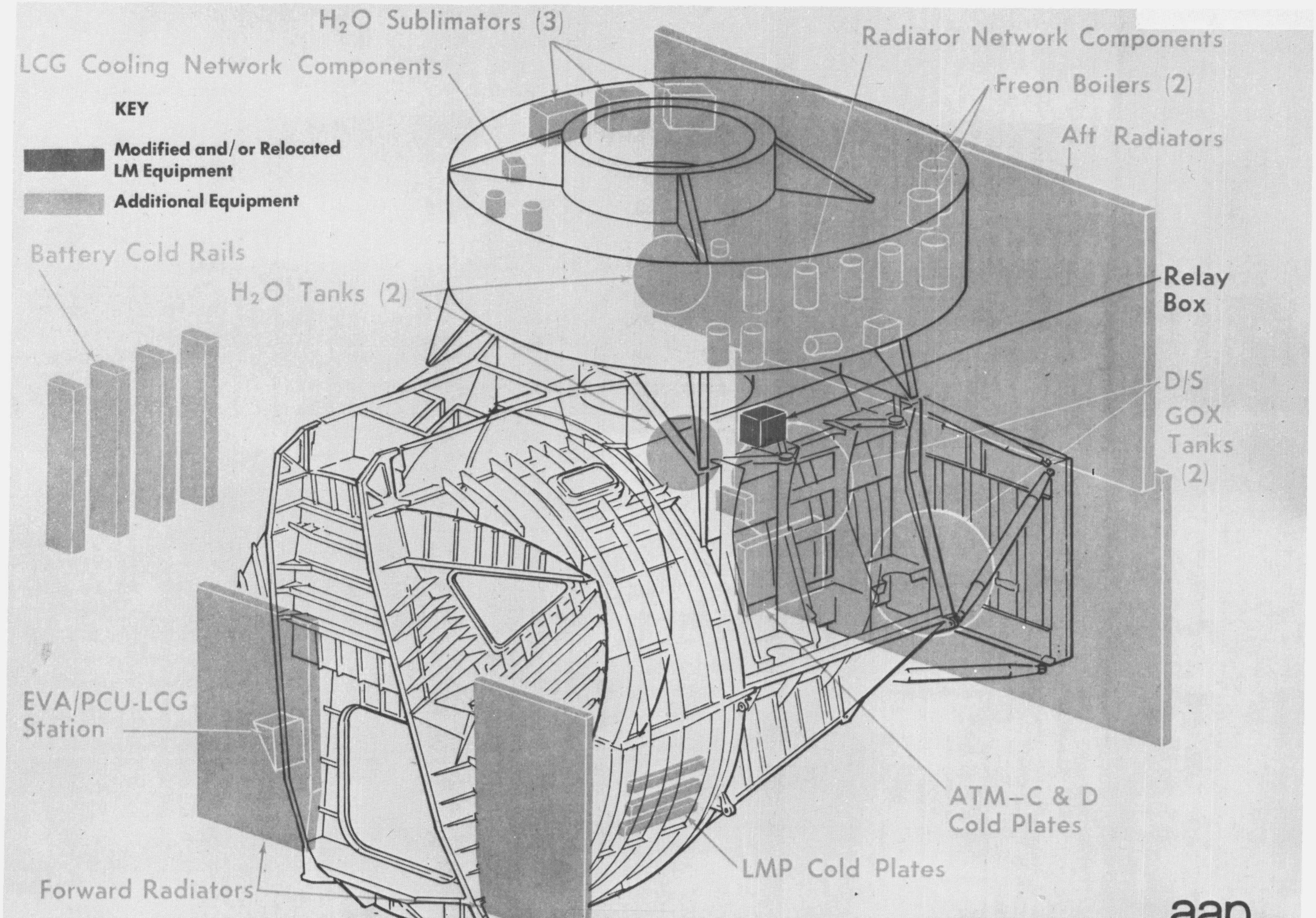


FIGURE 11. LM-A ENVIRONMENTAL CONTROL SUBSYSTEM HARDWARE

BELLCOMM, INC.

Subject: LM-A Thermal Control System

From: D. P. Woodard

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